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STERILIZATION OF ELECTRONIC COMPONENTS OF SPACECRAFT (U)

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ABSTRACT

Contamination of celestial bodies with earth microorganisms might make studies of any extraterrestrial life impossible. Sterilization of heat and/or radiation sensitive electronic components presents a special problem. Using a flexible film germ-free isolator, internal contamination was demonstrated in only 11 of 166 components, including 9 of 101 capacitors. Moreover, the level of natural contamination is low and destruction of microorganisms is assessed in terms of probability. Therefore, development of adequate sterilization procedures is being approached by deliberate contamination, during manufacture, with bacterial spores of high resistance to heat and irradiation. The results obtained with some types of resistors and diodes are presented.

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INTRODUCTION

As pointed out by Lederberg (4), the best approach to direct studies of the possibility of extraterrestrial life involves microorganisms, since they are (1) an early stage in the evolutionary process, (2) ubiquitous on our planet and probably any other planet containing life, (3) easily cultivated, and (4) best adapted to automation and telemetry in unmanned space vehicles. However, such studies would be seriously hampered, or even made forever impossible by inadvertent contamination with earth microorganisms deposited as a result of hard landings of space probes (1, 3, 4, 5, 7, 8) (figure 1). It is believed by some that earth microorganisms might well multiply on Mars (1, 2, 3). Such multiplication would not only interfere with determining the presence or absence of an indigenous flora, but by overgrowth might also jeopardize any possible use of extraterrestrial organisms for benefit of man (4).

Contamination of the moon with earth microorganisms would also jeopardize a most intriguing test of the panspermia hypothesis of Arrhenius, whereby spores drifted through space and seeded suitable planets. Having only a trace atmosphere, the moon has been envisioned as a trap for meteoroidal material (4), and is supposedly covered by a layer of cosmic dust (5). Although the surface temperature is estimated to range from +100 C. during the day to -150 C. at night, it has been estimated that at a depth of less than ½ meter, the temperature range is 0 to -70 C. Admittedly the ultraviolet radiation intensity on the surface of the moon is capable of killing all known microorganisms in a few hours, but Sagan (6) believes that microorganisms just beneath the surface, and thus protected from ultraviolet radiation, would survive cosmic radiation for a few hundred million years. Since the likelihood of a persistent indigenous flora is remote, the presence of microorganisms in the "moondust" would constitute evidence for the panspermia hypothesis.

Because of extremely low frictional resistance of the present trace atmosphere of the moon, it was recently stated by Phillips and Hoffman (6) that a single hard landing of a rocket could scatter bacteria over the entire surface of the satellite. As pointed out by Davies and Comuntzis (1), this possibility would be especially serious if a mammal were aboard, since there would be on the order of 10^{12} microorganisms present per kg of intestine. As the moon's surface is 4×10^{13} m², the microorganisms from one mammal might give rise to a serious degree of contamination, especially since the density of any organisms trapped from cosmic infall would be expected to be small.

It has been pointed out (1, 7) that organisms might easily survive a space journey. Ultraviolet radiation in space, while admittedly lethal to any known microorganism in a few hours, would only be effective against organisms on the outside surface of a space probe. Furthermore, vacua actually aid in preservation of microorganisms, although it must be admitted that no data are available on the effects of vacua with residual pressures lower than 10^{-9} mm of mercury. Finally, it has been pointed out that entry into the atmosphere of Venus or Mars would not necessarily result in a probe being consumed by heat (1, 4). The atmosphere of Mars is mostly nitrogen, with only a trace of oxygen, while that of Venus is chiefly carbon dioxide.

In view of these considerations, there has been a great deal of concern over the question of contamination of celestial bodies with terrestrial microorganisms (1, 3, 4, 5, 7, 8). Conversely, the possibility of contamination of the earth with microorganisms from a celestial body is no less worthy of sober consideration. It is theoretically possible that microorganisms brought back from the moon or Mars might be capable of causing a new human, animal, or plant disease.

It would thus appear that rigorous measures are needed to insure the absence of viable microorganisms in a space vehicle prior to its launch. Davies and Comuntzis (1) have recommended sterile assembly, built-in disinfection and terminal sterilization. Sterile assembly may be aseptic or antiseptic. Aseptic assembly involves fabrication of sterilized components into subsystems, and sealing these subsystems to prevent recontamination. An example of antiseptic assembly would be the application of liquid wipe-on sterilants, such as formaldehyde in methanol, to all mating surfaces not accessible to gaseous disinfectant, e.g., nuts, bolts, screws, etc. Built-in sterilization might be useful in fabrication of certain components; e.g., paraformaldehyde might be included in plastic used for potting electronic components (7). In any case, terminal sterilization, particularly of the interior of any space vehicle, appears essential.

Suggested methods of terminal sterilization have included the use of (1) heat, (2) radiation, and (3) chemicals. A priori, heat sterilization appears most desirable. However, as emphasized by Davies and Comuntzis (1), the function of certain types of spacecraft components is impaired by commonly employed regimens using heat. With regard to terminal sterilization by radiation, formidable practical difficulties are involved, as pointed out by Phillips and Hoffman (7). Furthermore, Davies and Comuntzis (1) found that certain types of components would not tolerate sterilization by radiation. For terminal sterilization by chemical means, it appears that agents active in the vapor phase are most feasible. Of the gaseous disinfectants, ethylene oxide is generally considered the agent of choice for space vehicles (1, 4, 7).

Overall spacecraft sterilization procedures now employed include:

1. Internal sterilization of components.
2. Aseptic fabrication of subsystems.
3. Aseptic installation of subsystems to spacecraft.
4. Terminal sterilization of surfaces of spacecraft in a sealed compartment.
5. Maintenance of sterilization.

A special problem in spacecraft sterilization concerns the interior of hermetically sealed electronic components. Obviously gaseous disinfectants cannot be used, and impairment of function may occur with methods involving heat (1) or radiation (1). A factor of prime importance in this problem, as in any sterilization problem, is a knowledge of the level of bacterial contamination. It is the purpose of this paper to present findings concerning the frequency of natural contamination, and an experimental approach to the development of adequate sterilization procedures for electronic components.

EXPERIMENTAL

Studies to determine the presence and level of natural contamination are generally carried out inside some sort of inclosure which has been made virtually gas-tight, so that the interior of the inclosure and the exterior of the components can be sterilized with a gaseous disinfectant. In our laboratory a germ-free isolator has been used, as shown in figure 2. As seen in figure 3, the tools used to disassemble the components are sterilized inside the isolator along with the exterior of the electronic devices themselves. To facilitate detection of any contaminating organisms which may be present in the interior of the components, it is essential to reduce all nonmetallic covering materials to a relatively finely divided state and to expose all internal surfaces. Recently it was found that one capacitor approximately 2½ inches in length by 1 inch in diameter contained, when completely unrolled, a surface area of about 50 square feet. Of a total of 166 components examined in our laboratory, 11 were contaminated. Of 101 capacitors cultured, 9 showed bacteria. Our findings on capacitors confirm those of Phillips and Hoffman (7), who reported 13 of 60 contaminated.

Many components are exposed during manufacture to temperature-time intervals that would appear, a priori, sufficient for sterilization. However, temperature-time data for killing bacteria are usually obtained by exposing dried spores on surfaces of such materials as glass, polished metal, and filter paper. There is no assurance that similar exposures would be adequate for destruction of the same microorganisms in the interior of electronic components.

In a strict sense, the killing of bacteria is a process whose result can be assessed only in terms of probability. Organisms generally die logarithmically, i.e., the logarithm of survivors plotted against time yields a straight line. For example, a given

heat-treatment may be said to result in 99.99 percent killing. Therefore, intelligent assessment of sterilization routines can be accomplished only with reference to definite levels of contamination. As indicated above, natural contamination of electronic components is sporadic; hence quantitative levels of microorganisms in the contaminated components would presumably vary widely.

In view of these considerations, it is suggested that development of adequate sterilization procedures for sealed electronic components be accomplished by use of components which have been deliberately contaminated during manufacture. Such an experimental approach should include the following stages:

1. Selection of appropriate microorganisms with high resistance to dry heat and/or radiation.
2. Contamination, during manufacture, of the interior of components with standard high cell concentrations (1×10^5 to 1×10^6).
3. Performance tests of assembled contaminated components.
4. Exposure of contaminated components to dry heat time-temperature and/or radiation regimens
5. Performance tests on heated and/or irradiated contaminated components.
6. Bacteriologic examination of undamaged components.

A joint in-house and contractual research program along the lines just detailed is in progress. Currently, spores of Bacillus stearothermophilus FS1518, suspended in acetone, are being used. The selection of FS1518 spores was determined not only on the basis of resistance to dry heat and radiation, but also to their ability to survive in a volatile liquid vehicle which does not damage the material to be contaminated. Recent data, however, by Koesterer and Bruch (9), and Davis et al. (10) seem to indicate that the spores of Bacillus subtilis var niger are more resistant to heat than FS1518 spores. The resistance of B. niger spores to radiation and their survival in acetone is being investigated. To date, four types of resistors (9 each) and two types of diodes (10 each) have been examined. The results indicate that for these types of components, normal manufacturing procedures are sufficient for sterilization.

SUMMARY

The importance of spacecraft sterilization has been discussed. Hermetically sealed electronic components constitute a special problem. Cultural techniques for such components have been described, and findings presented on the frequency of contamination. An experimental scheme for development of adequate sterilization procedures has been outlined, based on deliberate contamination during component manufacture. With the types of resistors and diodes tested to date, manufacturing procedures appear sufficient for sterilization.

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TABLE I

Results of the Different Types of Electronic Components Examined.

Type of Component	Number Examined	Number Positive
Capacitors	101	9
Resistors	45	0
Diodes	5	0
Electronic tubes	5	0
Relays	2	0
Transformers	4	1
Magnetic modulator	1	1
Micropositioner	1	0
Potentiometers	2	0
Totals	166	11

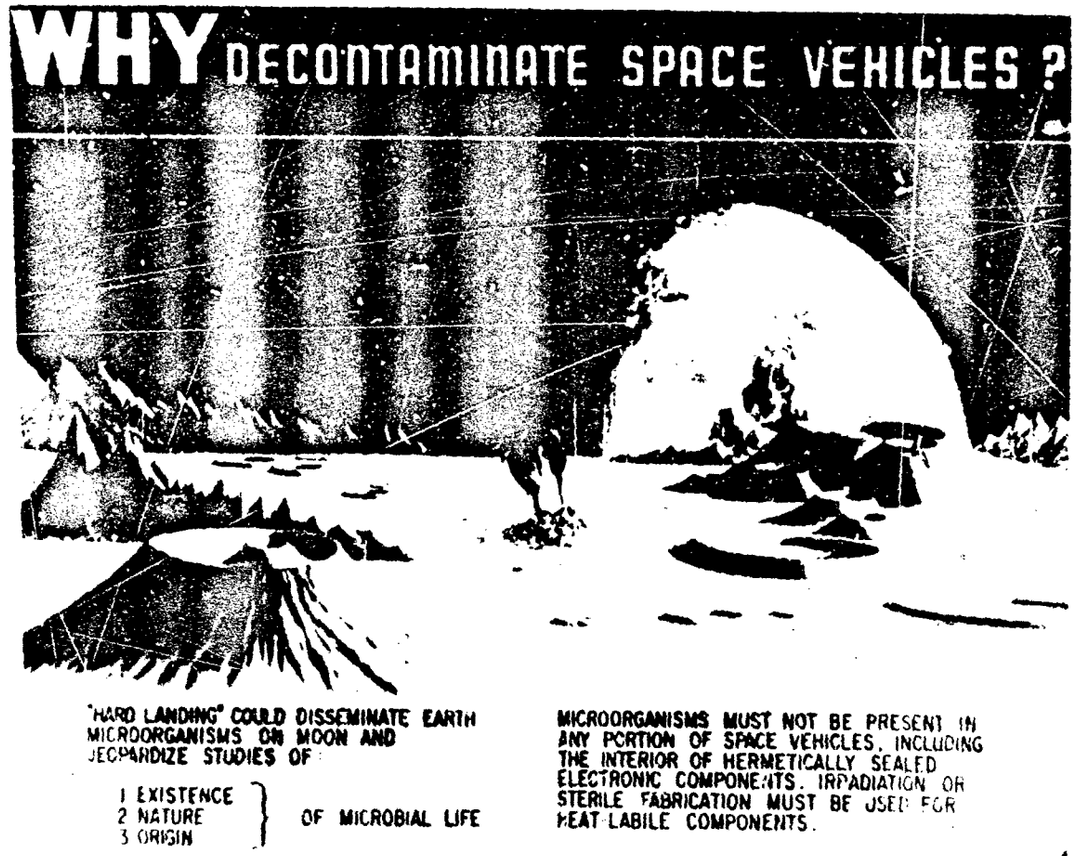

Figure 1 Hard Lunar Impact

AFPS SA AUG 65. 200

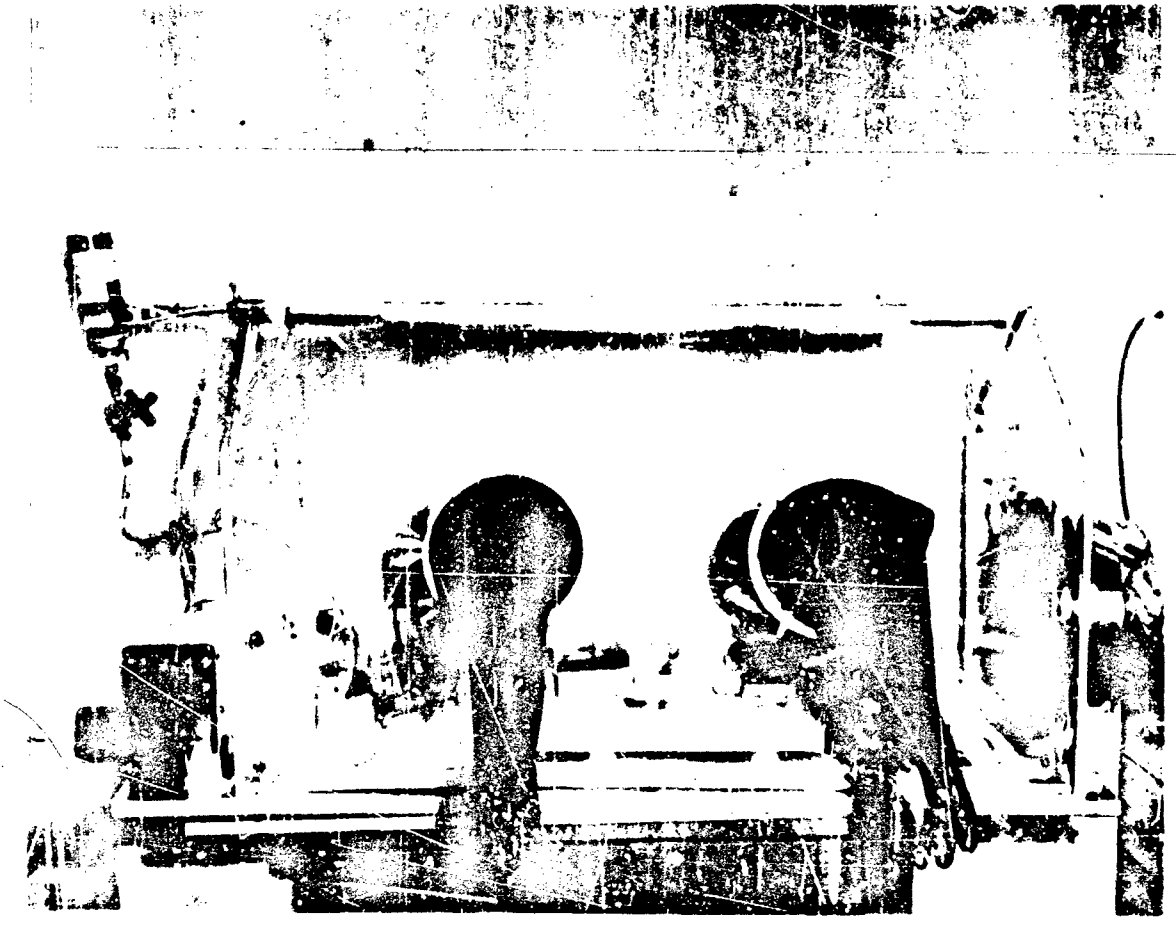

FIGURE 2. Flexible Film Germ-Free Isolator

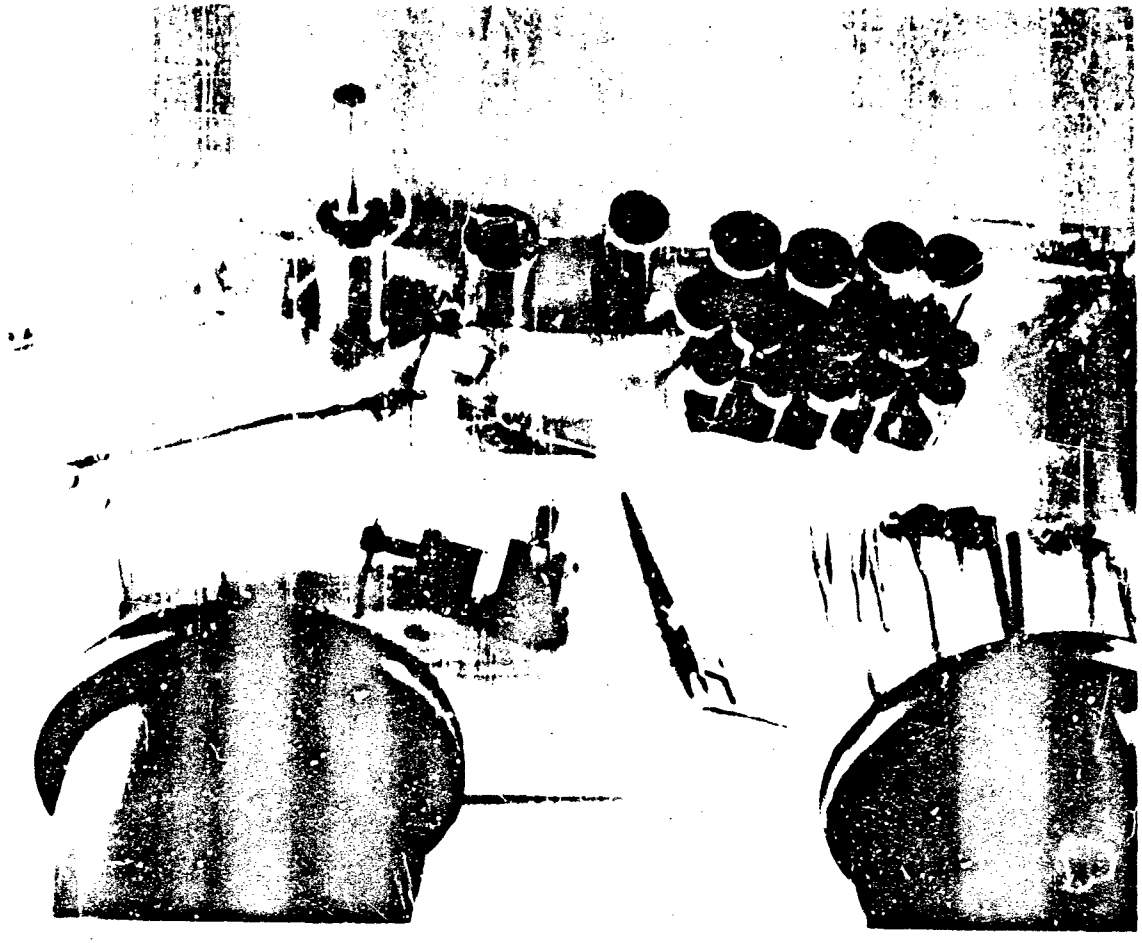

Figure 3 — Interior of Germ-Free Isolator